

What Is the Fire Danger Now? Linking Fuel Inventories with Atmospheric Data

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ABSTRACT

The combination of forest fuel maps with real-time atmospheric data may enable the creation of more dynamic and comprehensive assessments of fire danger. The goal of this study was to combine fuel maps, based on data from the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, with real-time atmospheric data for the creation of a more dynamic index of fire danger. Results indicated fuel loadings and moisture could be estimated for specific points on a meteorological modeling grid network (4×4 km; based on FIA's strategic-scale fuel inventory and atmospheric data) enabling the current assessment and 1- to 2-day prediction of fire danger as well as refined understanding of fire danger across forest ecosystems.

Keywords: fire danger, fine woody fuels, Forest Inventory and Analysis, mesoscale

Fire danger is defined in terms of factors affecting fire inception, spread, resistance to control, and subsequent damage (National Wildfire Coordinating Group 1996). Fire danger usually is expressed as an index based on component variables and is quantified using fire danger rating or prediction systems such as the US National Fire Danger Rating System (Deeming et al. 1977) and the Canadian Forest Fire Danger Rating System (Stocks et al. 1989). Fire behavior models use fuel loading (FL) and fuel moisture information to predict fire behavior, which, in turn, contributes to the development of fire danger rating systems (Andrews 1986, Finney 1998). FLs often are static for timescales of hours and days, whereas fuel moisture is variable across timescales of an hour or less. FLs and fuel moisture are both spatially variable at small scales (e.g., stand level), but fuel moisture is difficult to measure accurately because of high variability over short time-

scales. As a result, spatially averaged fuel moisture observations generally are used in fire danger assessments over large areas. To better mesh the collection and integration of FLs and moisture in fire behavior prediction models, the National Fire Danger Rating System (NFDRS) classifies FLs by fuel-hour classes (Deeming et al. 1977). For example, a 1-hour fuel is downed woody material with moisture fluctuations at the timescale of hours and is characterized by diameters of less than 0.25 in. Fuel hour classes with moisture fluctuations at greater timescales are larger in size. For the fire danger of any forest area to be determined, estimates of its FLs and moisture need to be assessed in real time and incorporated into a fire danger index.

Despite extensive work over the past decades to quantify fire behavior and subsequent fire danger, inadequate data and technology has impeded real-time assessments of fire dangers. Modern fuel inventories and recent meteorological advances may provide

opportunities to determine and provide 1- to 2-day predictions of fire danger.

Large-Scale Fuel Inventories

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service conducts a three-phase inventory of forest attributes of the United States (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into approximately 6,000-ac hexagons with at least one permanent plot established in each hexagon. In phase 1, the population of interest is stratified and plots are assigned to strata for purposes of increasing the precision of estimates. In phase 2, tree and site attributes are measured for plots established in the 6,000-ac hexagons. In phase 3, a one-sixteenth subset of phase 2 plots are measured for forest health indicators such as down woody materials. Down woody components observed by the FIA program are coarse woody, fine woody, litter, herb/shrubs, slash, duff, and fuel bed depth. As defined by the FIA program, fine woody debris (FWD) are downed woody materials with transect diameters less than 3.00 in. FWD are sampled on each FIA subplot along one transect. One- and 10-hour FWD (transect diameters between 0–0.25 and 0.26–1.0 in., respectively) are sampled along a 6-ft transect and 100-hour fine woody fuels (1.0–3.0 in.) are sampled along a 10-ft transect. For additional sampling design information see Woodall and Williams (2005).

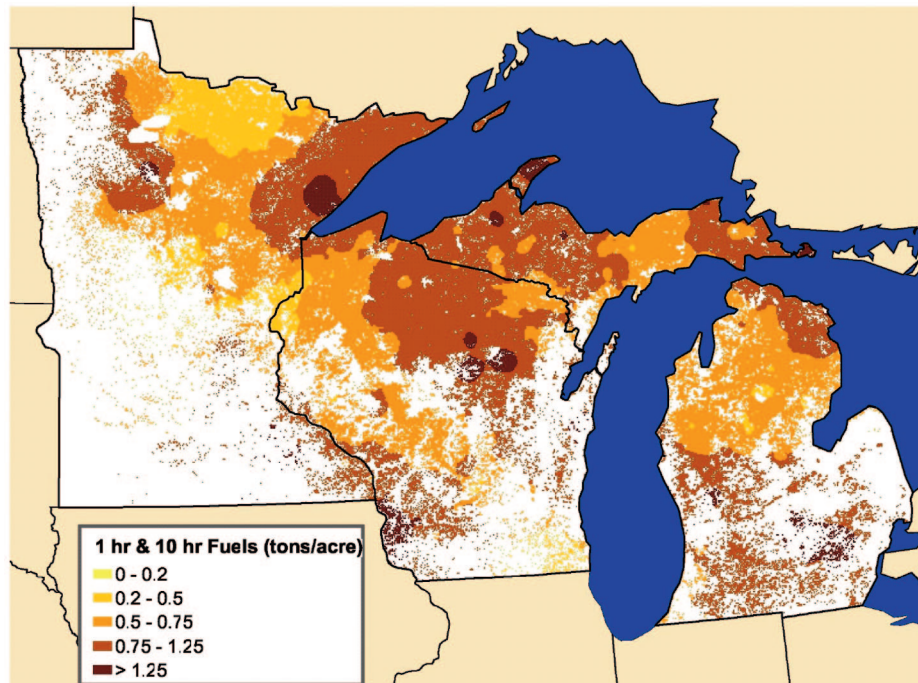


Figure 1. Regional map of FWD based on inverse distance weighting interpolation of 500 FIA fuel inventory plots and nonforest mask (classified NLCD 1992 imagery) in the upper Great Lakes region.

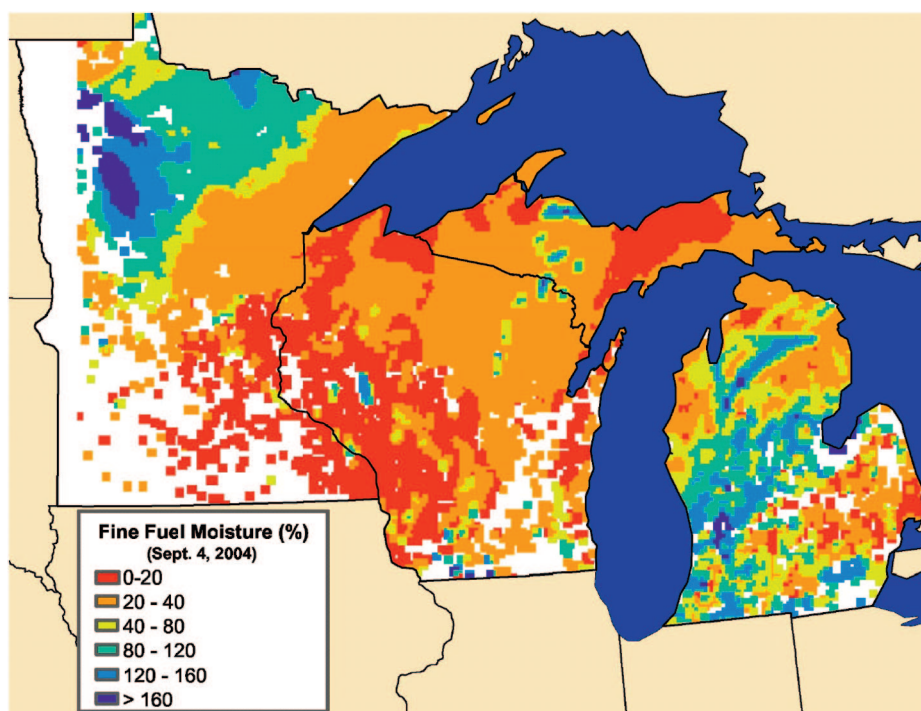


Figure 2. Fine woody (1- and 10-hour) fuel moisture map for study area, upper Great Lakes, Sept. 4, 2004.

The FWD sampled by the FIA program match the fuel classification system (1, 10, and 100 hours) of the NFDERS, allowing creation of strategic-scale fuel maps that may be used to assess fire danger (Woodall et al. 2004). Because of the relatively sparse sample intensity of the FIA fuels inventory, in-

verse distance weighting interpolation techniques may be used to predict FLs between sample plots. After fuel interpolation, non-forested areas are masked out of the fuel maps using classified imagery such as the National Land Cover Dataset (Vogelmann et al. 2001), as used in this study (Figure 1).

Numerous techniques are available for creating large-scale fuel maps ranging from relatively simple interpolation techniques of FIA fuels data, as used in this study, to more sophisticated efforts established by Rollins et al. (2004) and the Forest Service's LAND-FIRE program (USDA Forest Service).

Fuel Moisture and Mesoscale Models

Estimates of surface fuels and real-time weather data are both necessary to estimate fuel moisture conditions and fire danger. Numerical weather prediction models can produce daily simulations of atmospheric conditions such as temperature, winds, relative humidity, and rainfall for regions ranging in size from continents to counties. One such model, the Penn State University/National Center for Atmospheric Research Mesoscale Model (MM5), simulates the weather conditions for areas of about one-third the size of a continent down to state and county levels (Grell et al. 1994). The MM5 "mesoscale" model can be run daily, using observations collected and processed at the beginning of each day, to produce a sequence of 24-hour simulations of weather conditions across a region.

The Eastern Area Modeling Consortium (EAMC) is a multiagency coalition of researchers, fire managers, air quality managers, and natural resource managers working to conduct research and develop new products to improve fire-weather and smoke transport predictions in the north central and northeastern United States. The EAMC runs the MM5 daily for the north central and northeastern United States in support of fire-weather research and applications. One application of this atmospheric data uses the Canadian Fire Weather Index System (CFWI; Van Wagner 1987) to calculate fuel moisture variations across the model geographic domains based on simulated temperature, relative humidity, and rainfall information. These calculations use the Fine Fuel Moisture Code in the CFWI system to generate daily values for fuel moisture that roughly correspond to the expected variations in 1- and 10-hour fuels, as defined by the NFDRS. Fine fuel moisture estimates from the EAMC's mesoscale models may be produced for any forest ecosystems on any given day (Figure 2).

Merging Fuels and Moisture Estimates

To create a more dynamic regional view of fire danger, we sought to combine maps of regional FLs (interpolated FIA fuel map, Figure 1) and fuel moisture (EAMC mesoscale models; Figure 2) for the upper Great Lakes. First, FLs (1- and 10-hour FWD) were obtained from FIA's interpolated fuel maps for a 4×4 -km grid (13,136 forested

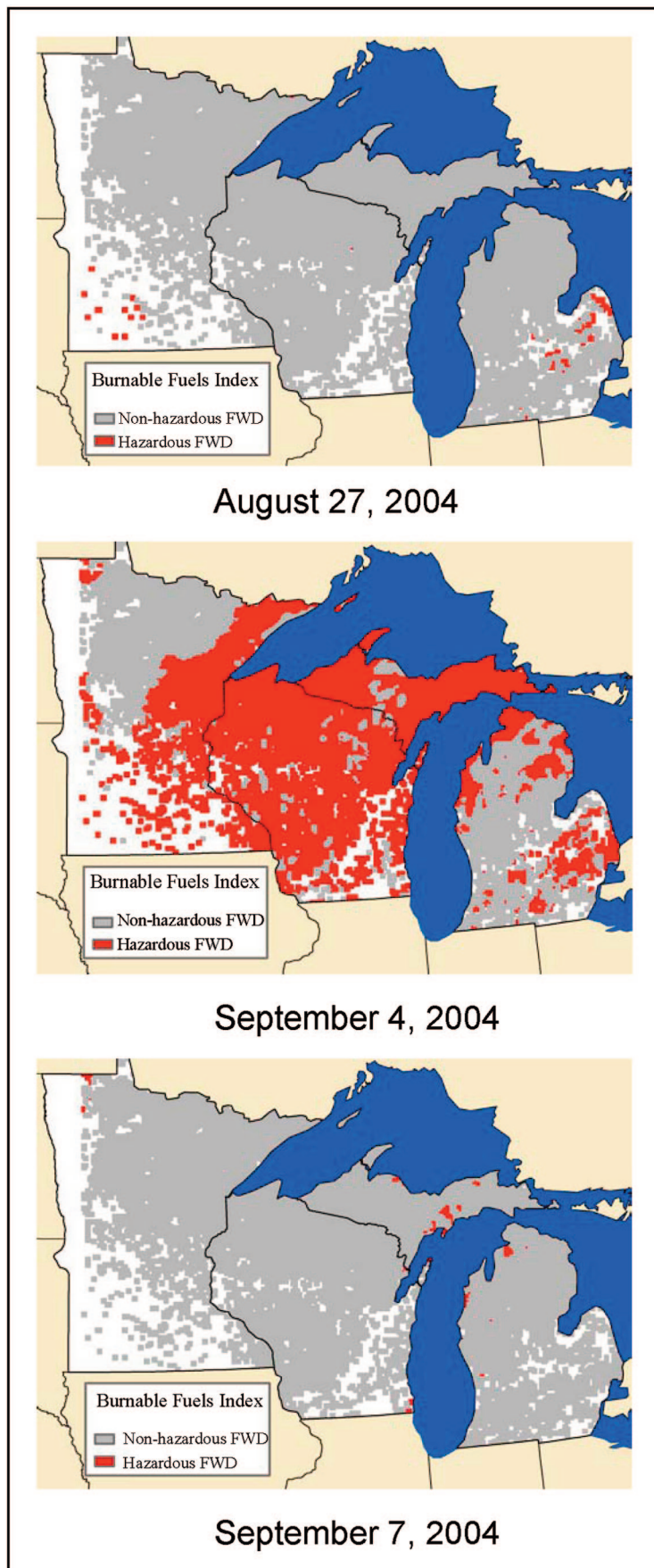


Figure 3. BFI before (Aug. 27), during (Sept. 4), and after (Sept. 7) a major weather event over a 3-day time step during the summer of 2004 (upper Great Lakes).

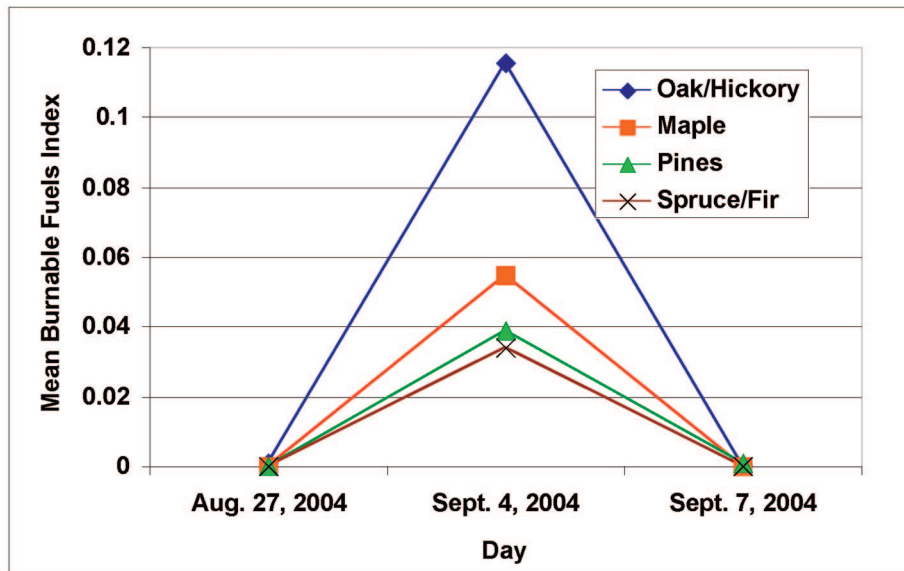


Figure 4. Mean BFI (all nonhazardous areas given a BFI of zero) by forest type over a 3-day time step (summer 2004, upper Great Lakes).

grid points) across the upper Great Lakes used by the EAMC's mesoscale model. Second, to address the effects of FL and fuel moisture, the two estimates were combined into a single meaningful quantity that is applicable to operational fire activities. As a rule of thumb, fire danger can be considered to increase when fuel moistures fall below 30%, which is the fiber saturation point in dead fuels (Zhou et al. 2005). To accentuate the effects of this generalized threshold, we developed the Burnable Fuels Index (BFI), formulated as

$$\text{BFI} = (0.3 - m) \text{FL}$$

where m is the simulated fuel moisture between 0 and 1 (0 and 100%) and FL is in tons/acre. BFI is negative when fuel moistures exceed 30%. Conversely, BFI will increase as fuel moistures decrease below 30% and as FLs increase. This quantity offers no insight into the probability of ignition and does not account for long-term precipitation effects on the heavier fuels. It is most useful when used in conjunction with observations of moisture variations in the heavier fuels and local knowledge of fuel and forest conditions. However, at strategic scales, BFI may aid comprehension of how fire danger varies by day and user-defined areas.

Dynamics of Fire Danger

In the upper Great Lakes region of the United States, fire danger may vary daily over a fire season. Results from this study indicated dangers from 1- and 10-hour fuels varied from almost no danger (Aug. 27 and

Sept. 7, 2004) to moderate danger (Sept. 4, 2004) during a span of a few days (Figure 3). Areas with positive BFI (hazardous FWD) were typically constrained to areas that had dried out after the precipitation of recent weather fronts and before the arrival of a new weather front (Figure 3). Linking real-time estimates of fuel moisture with static fuel maps may allow refinement of fire behavior predictions and subsequent wildland firefighting efforts.

Estimates of BFI across the upper Great Lakes were linked with estimates of forest types (Zhu and Evans 1994) to determine mean BFI by day for common forest types. To exclude areas that had nonhazardous FWD, all negative BFI values were set to zero to reflect their moisture-saturated state. Results indicate that not only does fire danger vary by day, it also varies substantially by forest type (Figure 4). All forest types had mean BFIs near zero during precipitation-laden weather events indicating fuel moistures in excess of 30%. However, during dry spells (Sept. 4, 2004), fire danger increased to varying levels by forest types. The hardwood forest types of oak/hickory and maple had the highest mean BFI during the dry spell whereas the conifer forest types of pines and spruce/fir had less increase in fire danger. These results may be attributed to higher FWD FLs among the Great Lake's hardwood forest types and the driest areas on Sept. 4 being dominated by hardwood forest types (central Wisconsin).

This study's generalization of fire dangers across large scales and diverse forest

types does not directly aid local fire/fuels management efforts (e.g., prescribed burning). However, this study's results enable assessment of fire dangers at the landscape level to broadly understand danger variations by forest type and weather event. Although in hindsight, knowing that on Sept. 4, 2004 hardwood forests of the Great Lakes were at risk of ignition may have little use for the fire managers, comprehending fire danger dynamics in response to weather events across this country's diverse forest ecosystems is critical for large-scale fire/fuels management efforts.

Real-Time Outputs and the Future

Regardless of the sources for strategic-scale FL and moisture maps (i.e., LANDFIRE, FIA inventories, or EAMC mesoscale models), these data can be combined to create real-time outputs such as BFI to estimate regional fire danger. On a daily time step, counties or other defined polygons with hazardous FWD may be identified (Figure 5). As shown by the example in this study, county-level fire danger may change considerably over very short time periods (Figure 5). Because the hazardous nature of FWD may vary on such a short time step, relaying safety information to the public and fire control information to firefighting crews is crucial.

Because this study served as an initial examination of the techniques and outputs of merging strategic-scale fuel maps with real-time weather data, numerous refinements

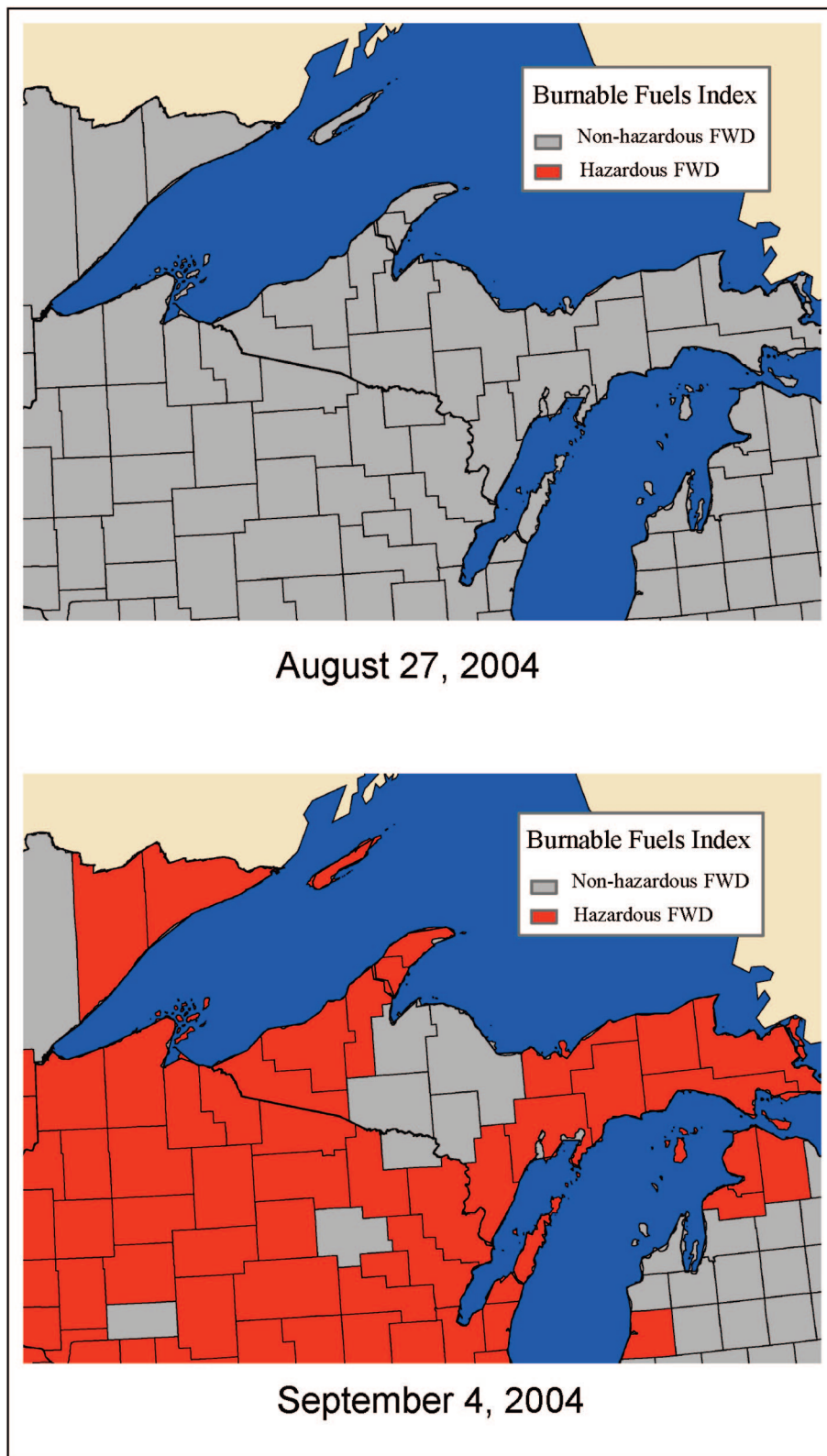


Figure 5. Mean BFI by county for separate days during the summer of 2004 (northern Great Lakes region).

need to be developed to allow widespread application. First, BFI is currently a proof of concept diagnostic that needs to better reflect fuel and fuel moisture relationships that

are likely not multiplicative. Second, although inverse-distance weighted interpolation of FIA phase 3 plots is an efficient and simple methodology for creating regional

fuel maps, other techniques and data sources exist to complement and further improve regional fuel data layers. Third, because of the variety of fuel types across the country, the general methodology of this study would need to be refined for application in other regions. Last, data dissemination techniques that facilitate real-time web updates of BFI maps are necessary to incorporate them into fire season activities. Overall, the results of this study indicate that opportunities exist to refine understanding of the dynamic nature of forest fire dangers.

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